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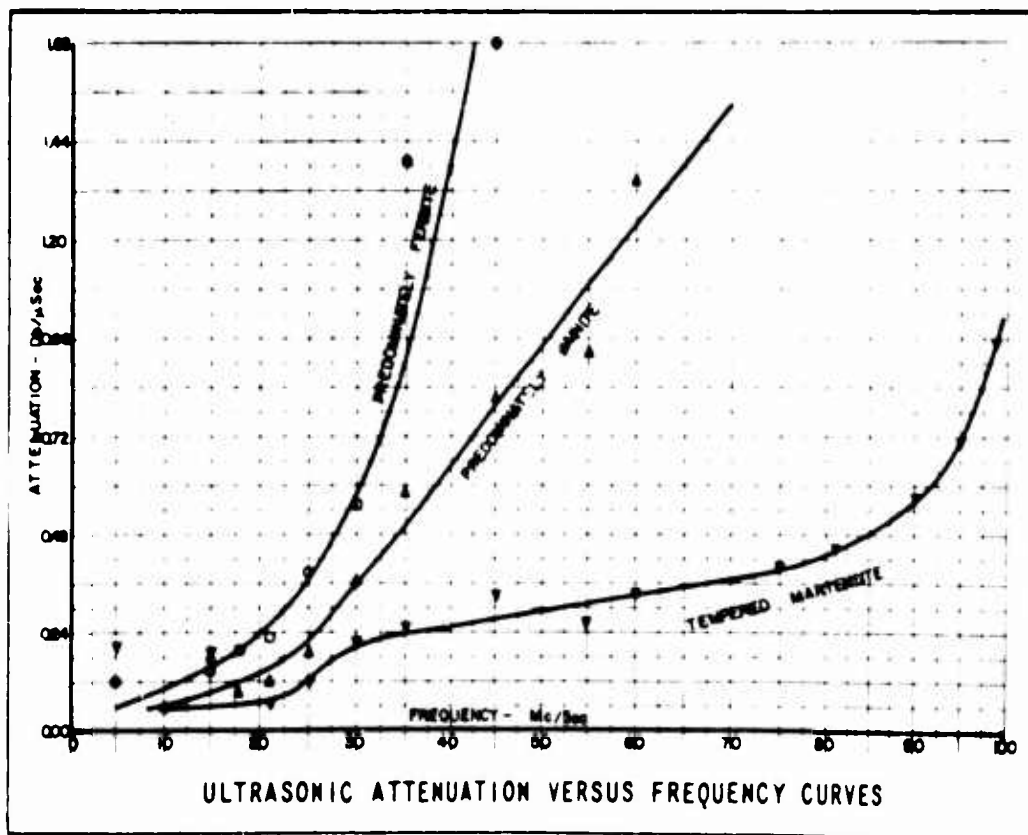
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ULTRASONIC ATTENUATION AND PHYSICAL PROPERTIES OF METALS

By

JOHN W. ORNER



ULTRASONIC ATTENUATION VERSUS FREQUENCY CURVES

NOVEMBER 1960

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Presented at  
Third International Conference on  
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21 March 1960  
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Ultrasonic attenuation or rate of energy absorption in a solid material is a complex function of many variables, and as the mechanism of attenuation is becoming better understood, a very valuable nondestructive testing tool is being made available for the determination of physical properties of metals. As the many variables exhibit differing frequency characteristics, theoretically it should be possible to isolate the individual effect of any one of them by an analysis of the attenuation versus frequency relationship. Applied research in this field is beginning to close the wide gap which exists between the work of the basic researchers and the application of their findings on the inspection level.

Whenever the word "Ultrasonics" is mentioned in connection with testing, it is perhaps only natural to think in terms of defect detection, as it is in this important field that ultrasonic techniques have proved their capabilities. However, it is perhaps safe to say that the most important aspect of ultrasonic testing is that much can be learned about solids from the propagational behavior of stress waves in them. The equation of motion for the amplitude of the stress waves involves two variable factors, the attenuation constant and the velocity of propagation. Both of these variables can be determined experimentally and related to physical characteristics of the solid material under test. It is, of course, necessary that the stress amplitude be small so that the elastic range of the material is not exceeded. Outside that range, the relation between stress amplitude and strain amplitude is no longer linear.

These two quantities, attenuation and velocity of propagation are rather involved functions of many variables, some of which can be listed as follows:

1. Frequency
2. Strain
3. Temperature
4. Strain cycling - Fatigue
5. Grain size and orientation
6. Radiation damage by neutrons, gamma rays, electrons and nuclear particles.

These and other variables indicate the potential possibilities of ultrasonic testing for the determination of the physical properties of metals. In order to make the fullest possible use of this valuable tool, it is, of course, necessary to investigate more fully the effects of all the variables on both attenuation and velocity phenomena. However, for the purpose of this paper, attenuation effects only will be considered. It should be mentioned, however, that as velocity is largely a function of the elastic constants, and the density of a solid, we have here a very useful tool for the determination of the elastic constants.

Before getting involved in a discussion of the practical aspects of ultrasonic attenuation measurements, it is perhaps important to consider just what one can really expect to learn from the data obtained.

It is possible to determine whether certain changes in materials arise because of effects that produce scattering, or effects that produce damping changes. This is important in connection with radiation effects in solids where the radiation may release point defects that pin dislocations, or defects which cause attenuation changes due to scattering phenomena.

In certain conditions, of deformation, it is possible to evaluate the effective dislocation density and effective loop length. The recovery phenomena following deformation has yielded information about the concentration and nature of defects.

In scattering phenomena, it is possible to make fairly good estimates of the size of the scattering centers. This is important in connection with radiation effects where, under certain conditions, a rough determination can be made of the sizes of regions of damage.

The effect of fatigue or stress cycling on ultrasonic attenuation has brought to light some very interesting possibilities. Attenuation changes are evident right from the first cycle which appear to be a combination of dislocation damping and scattering. There is no need to stress the importance of the practical application of the ultrasonic tool in this area.

Now, having had this brief review of some of the many variable factors that influence ultrasonic propagational characteristics in solids, let us look a little more closely at the possibilities of reducing this theoretical knowledge to practical application at the inspection level. Workers in the basic research field have provided us with the knowledge of the fundamental principles involved, and it is now the responsibility of the application engineers and scientists to devise means and techniques of applying this knowledge to our everyday problems of nondestructive testing.

One of the first big problems that arise is, of course, how is one to evaluate the effect of one of a great many variables, all operating together, by means of an experimental measurement on only one parameter? Fortunately, however, each one of these variable factors which contribute to ultrasonic attenuation has its own individual frequency dependence and, therefore, theoretically at least, it should be possible to isolate the effect of any one of them by means of an analysis of the attenuation versus frequency relationship. Practical research work along these lines is in progress.

Now, having briefly outlined some of the possibilities of ultrasonic attenuation testing, it might be relevant at this point to discuss the test technique itself.

Commercial equipment is readily available, which in experienced hands is capable of making accurate determinations of attenuation on carefully prepared specimens at frequencies ranging from one megacycle per second to about 200 megacycles per second. The ultrasonic energy is fed, in very short pulses, to a piezo-electric crystal which is acoustically coupled to the specimen under test by a thin film of liquid, such as oil or glycerine. The resulting ultrasonic waves then bounce back and forth in the specimen with constantly decreasing amplitude, as

shown in Figure 1. A measurement of attenuation can be made by means of comparison with the variable exponential curve.

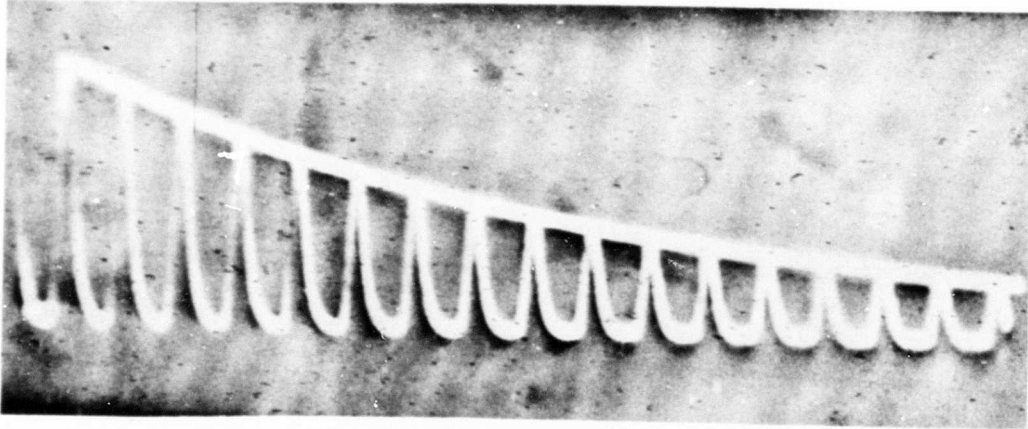


FIGURE 1: DISPLAY ON ULTRASONIC COMPARATOR

An example of a practical application of attenuation measurements to an inspection problem is illustrated in Figure 2.

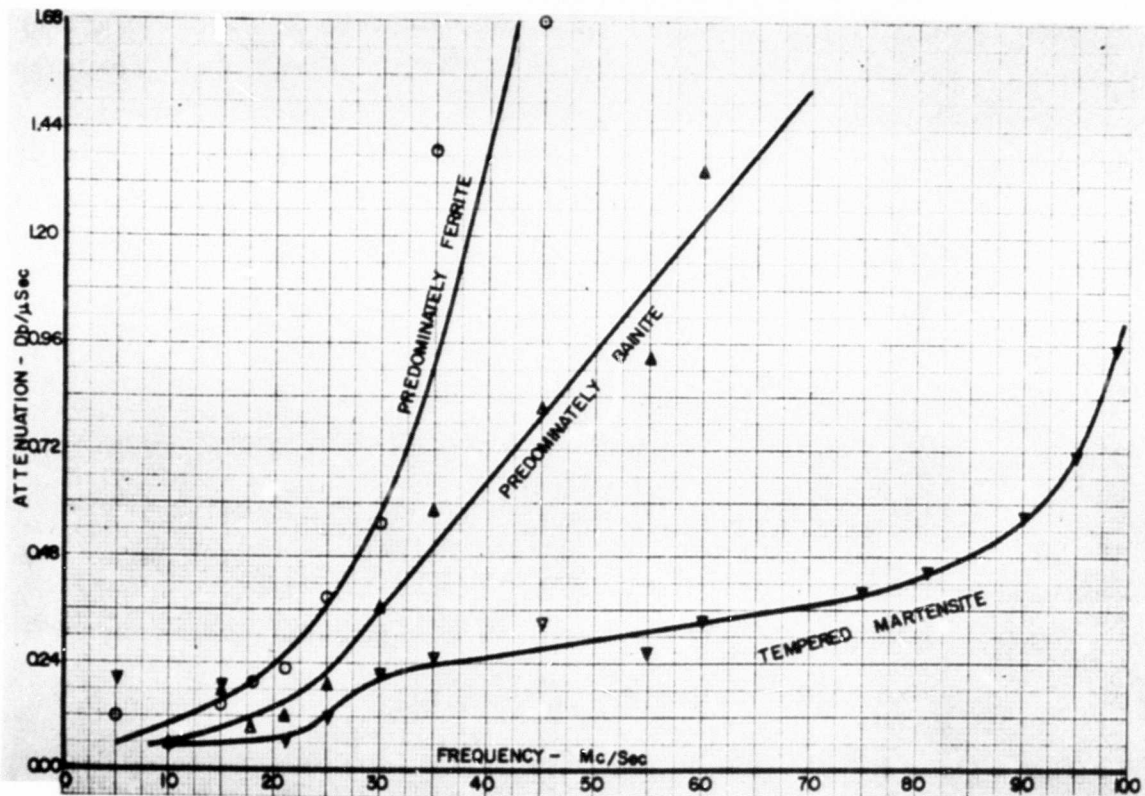
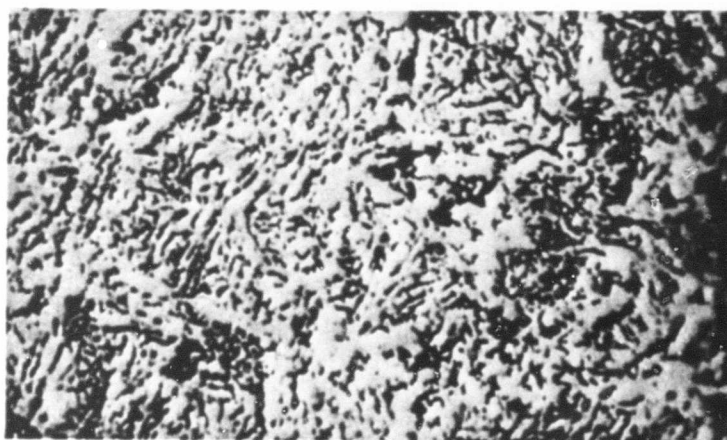


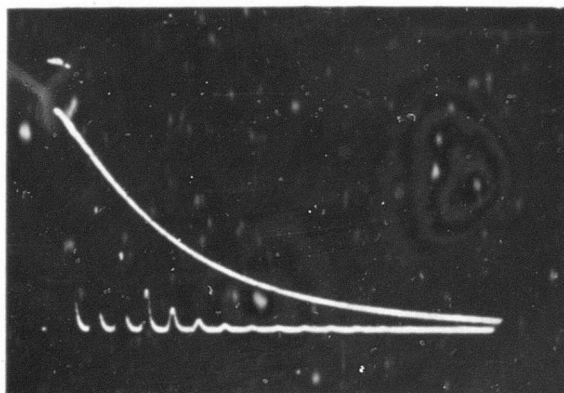
FIGURE 2: ULTRASONIC ATTENUATION VERSUS FREQUENCY CURVES

In this case, the problem was one of inspecting finished gun barrels for adequacy of heat treatment. Attenuation measurements were made, over a range of frequencies, on samples cut from barrels selected to represent examples ranging through poor to good in heat treated condition. Figure 3, 4 and 5 show photomicrographs representative of the extremes of the range encountered, and an intermediate case. The actual comparator indications are included in each case to show the differences evident at a frequency of 35 megacycles per second.



10% TEMPERED MARTENSITE

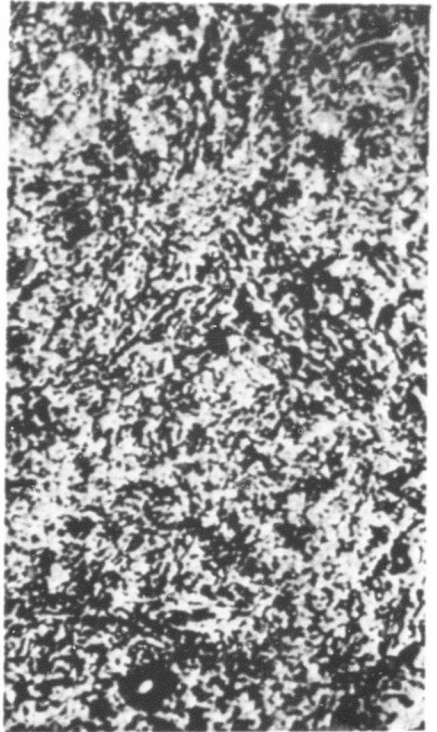
X1000



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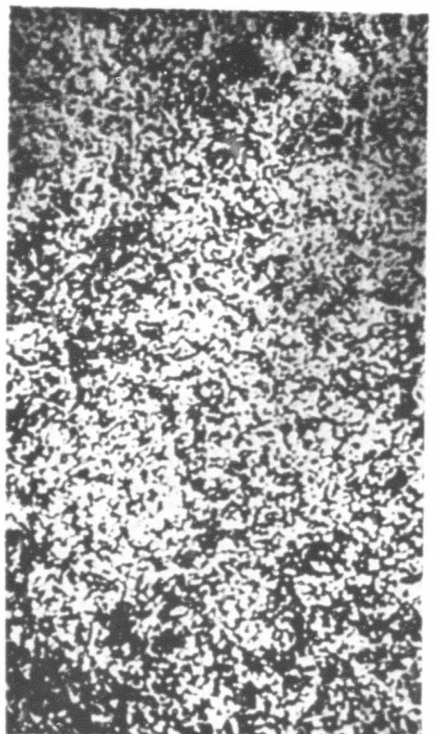
FIGURE 3: MICROSTRUCTURE VERSUS ULTRASONIC ATTENUATION PATTERN





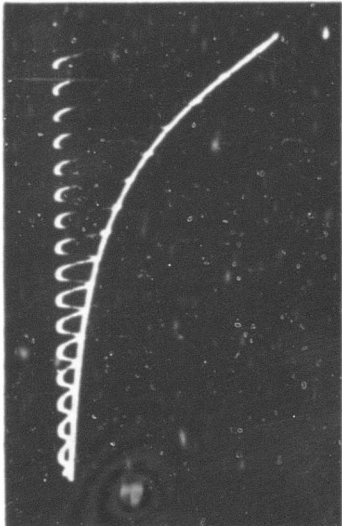
70% TEMPERED MARTENSITE

X1000



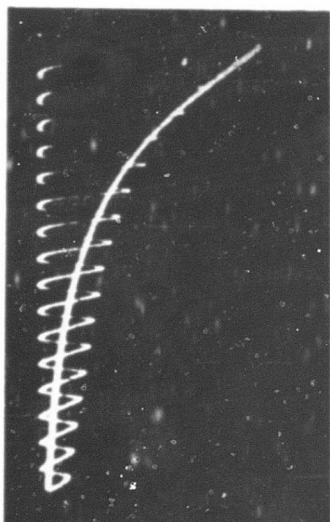
100% TEMPERED MARTENSITE

X1000



244272

FIGURE 4



294003

FIGURE 5

MICROSTRUCTURE VERSUS ULTRASONIC ATTENUATION PATTERN

For the nondestructive inspection of these barrels, a technique was developed whereby the crystal, in its holder, was applied directly to the periphery of the previously wetted barrel. The exponential comparison curve was set to the limiting value, and the gain control adjusted so that the first "pip" just touched this line. An acceptable condition was indicated if the peaks of the subsequent pips either reached, or rose above the exponential line.

It should be pointed out, however, that this test did not prove to be completely reliable, and it was necessary to supplement it with an additional screening process based on eddy currents. This second test, by itself, was not completely reliable either, but the combination of the two did give a high degree of assurance.

Further applied research underway at Watertown Arsenal is an investigation into the effects of heat treatment and grain size on attenuation in steel. In addition, interesting results have been obtained in connection with the condition known as burned aluminum in which excessive heat treating temperatures give rise to segregations forming at the grain boundaries with a consequent reduction in the strength of the material.

Perhaps it would be wise at about this point to attempt to counteract what seems to be a natural tendency to be unduly optimistic about the capabilities of any new nondestructive testing technique or method. Although our knowledge of the underlying principles of ultrasonic attenuation is now fairly good, application techniques are lagging far behind, and are severely limited. The collection of attenuation versus frequency data, and the correct interpretation of the results obtained are a long and tedious business and, in general, the chances of success in any given problem are by no means assured. However, applied research is making continuous progress towards solving the many problems involved, and we are perhaps justified in feeling somewhat optimistic about the eventual outcome.

In connection with an investigation of the effects of heat treatment on the ultrasonic attenuation in 24ST aluminum attenuation versus frequency data was plotted for seven different samples, as shown in Figure 6. Sample No. 1 was not heat treated, and was therefore in the "as-received" condition. No. 2 was treated at 930°F for 6-hours, then water quenched. The remaining samples were subjected to 6-hours at temperatures increasing by 20°F in each case. All samples were water quenched. With only one exception, the

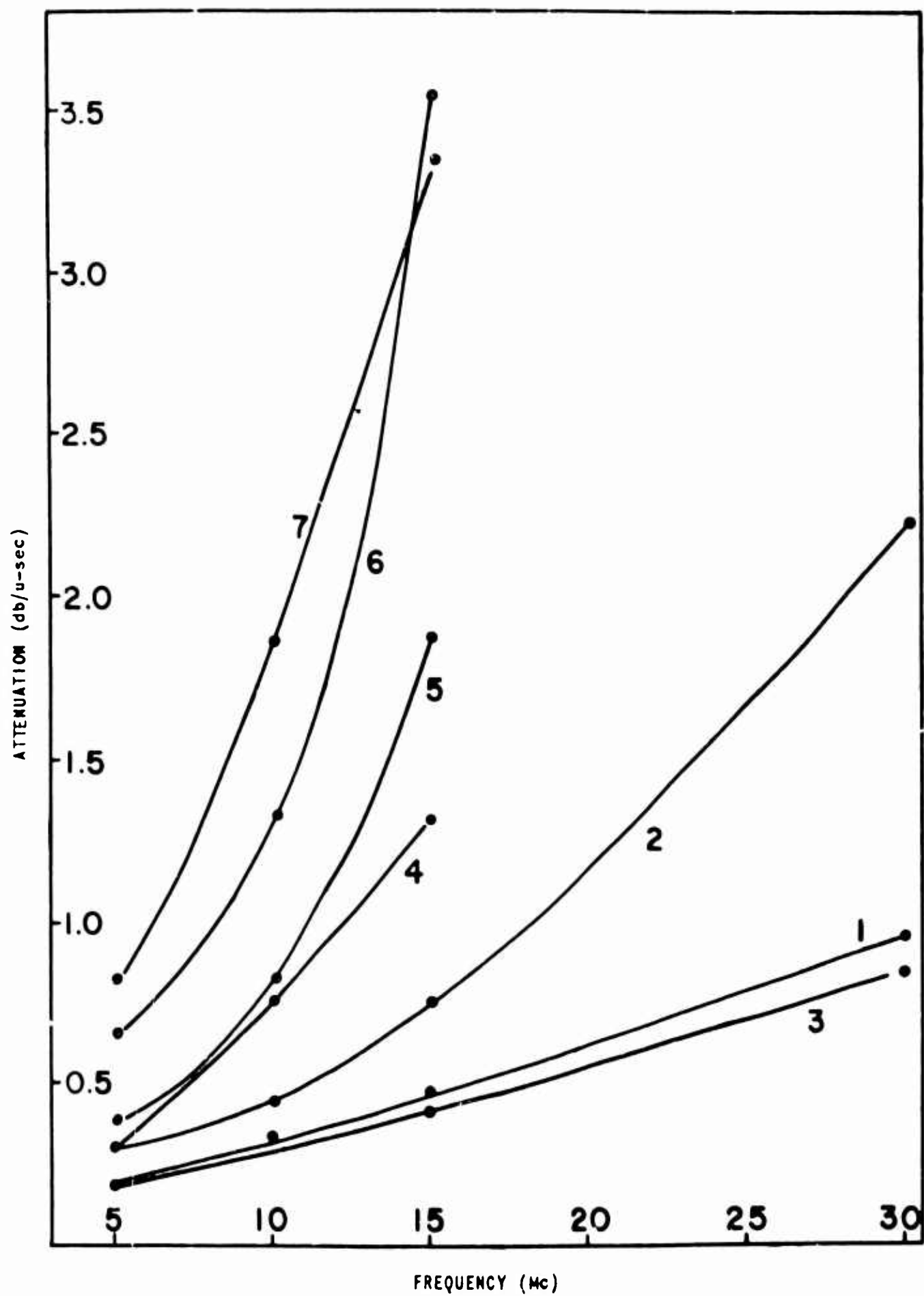


FIGURE 6: ATTENUATION VERSUS FREQUENCY

attenuations show a marked increase with rising heat treatment temperatures. The one exception is No. 3 which has the lowest attenuation of all. No satisfactory explanation was found for this apparent anomaly which is probably the result of some, up to now, unsuspected variable.

Metallographic examinations showed that grain boundary damage due to "burning" was evident with increasing severity from No. 4 (970°F) on up through No. 7.

The differences in attenuation as shown by these samples are practically negligible at 5 megacycles until we get into the range where burning damage becomes appreciable, after which very large changes occur, large enough in fact that they can easily be detected with a reflectoscope, and there is no need to use an attenuation comparator.

Figure 7 shows a photomicrograph of Sample No. 1 with its reflectoscope indication superimposed. Here the grain boundaries are clear and undamaged, and a large number of echoes appear on the reflectogram.

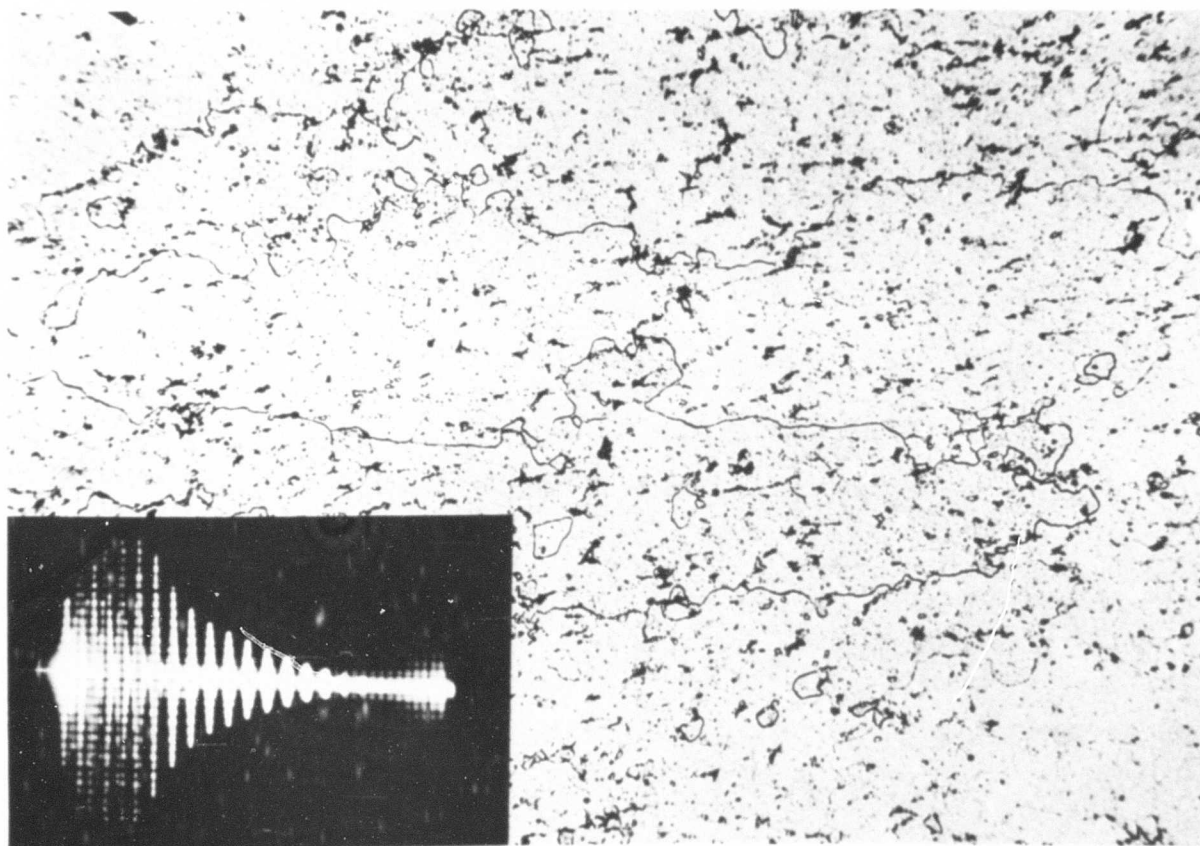


FIGURE 7: EXAMPLE OF UNBURNED ALUMINUM

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Figure 8 shows a similar photomicrograph and reflectogram of Sample No. 7. Note here the many grain boundaries that have been severely damaged by the segregations brought about by overheating, thus making the metal very susceptible to cracking. In addition, note the rapid absorption of the ultrasonic energy as shown on the reflectogram.

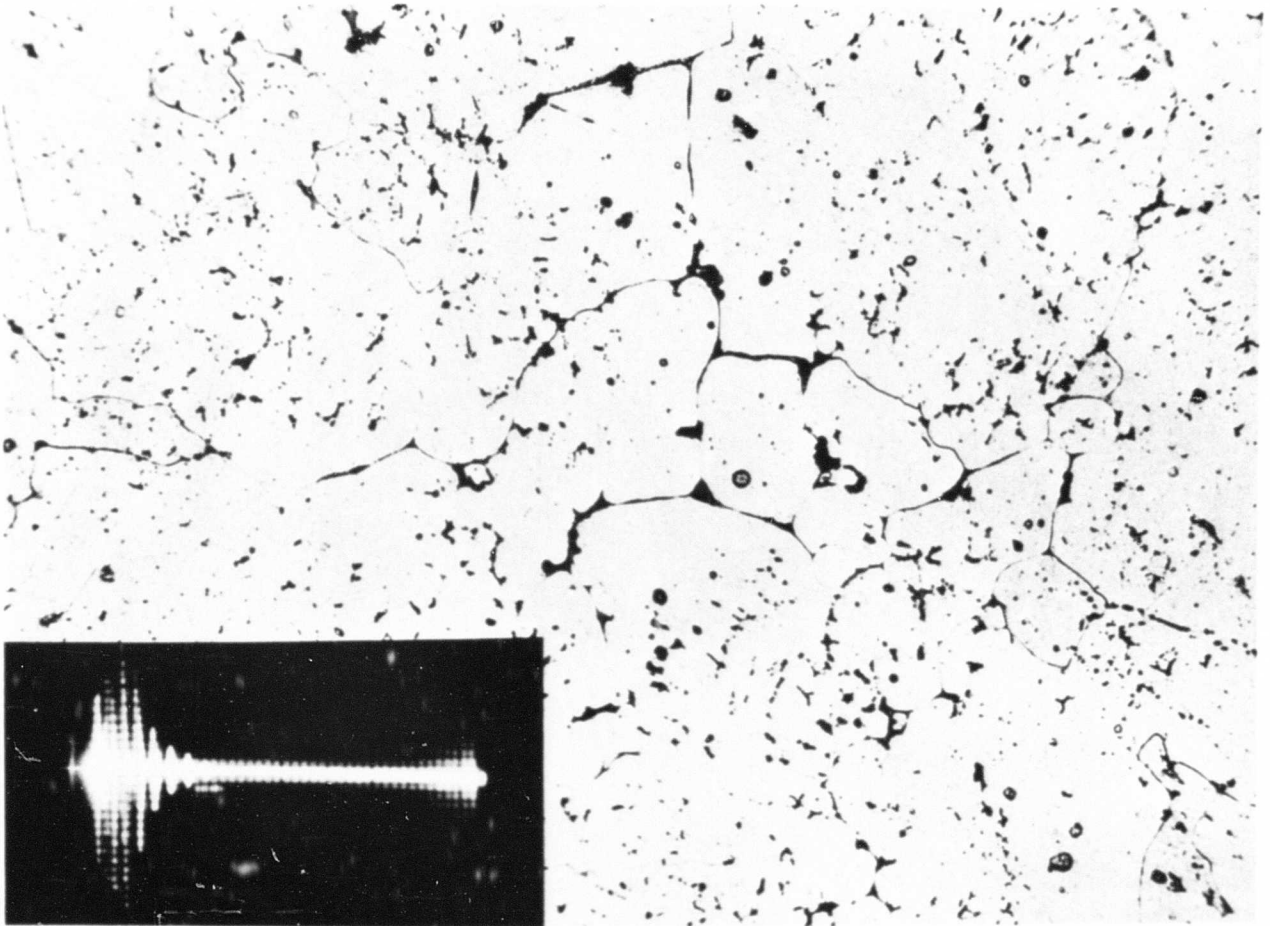


FIGURE 8: EXAMPLE OF BURNED ALUMINUM

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This particular investigation of 24ST aluminum was initiated by a request from an agency engaged in machining aluminum components. It had been noticed that there were numerous cases of cracking during machining, and a method was required for testing the unmachined metal for crack susceptibility. In this case, the principles of ultrasonic attenuation provided a simple and practical solution.

So we see now that though this whole question of using ultrasonic attenuation techniques for the determination of physical properties of metals is fraught with difficulties and uncertainties, at least progress is being made, and a limited measure of success has been achieved in certain areas. The fact that somewhat sophisticated determinations can and have been made under ideal laboratory conditions enable us to look forward with confidence to the day when improvements in instrumentation techniques and application methods will make possible the utilization of this potentially powerful tool for direct quality determinations right on the inspection level.